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A SMALL COMBINATION SENSING PROBE FOR MEASUREMENT OF TEMPERATURE, PRESSURE, AND FLOW DIRECTION

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ABSTRACT

The design features and characteristics of a small combination sensing probe for the measurement of total temperature, total pressure, and flow direction of a gas stream are presented. Also, with proper consideration, a flow-direction sensing hole indication can be used to determine static pressure. Experimental data are presented for the aerodynamic recovery and time response of the temperature sensor, the flow angle characteristics of the total pressure sensor, and the sensitivity of the flow direction wedge. These data were obtained over a subsonic Mach number range of $0.2 \leq M < 1$, as well as at $M = 1.4$.

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SUMMARY

The design features and characteristics of a small combination sensing probe for the measurement of total temperature, total pressure, and flow direction of a gas stream are presented. Also, with proper consideration, a flow direction sensing hole indication can be used to obtain static pressure. Experimental data are presented for the aerodynamic recovery and time response of the temperature sensor, the flow angle characteristics of the total pressure, sensor, and the sensitivity of the flow direction wedge. These data were obtained over a subsonic Mach number M range of $0.2 \leq M < 1$ as well as at $M = 1.4$.

The probe is intended to be used primarily in an actuating system capable of linear and rotational positioning, but information is presented whereby the probe may be used in a fixed position, and stream parameters can be determined from relations of the measured quantities.

INTRODUCTION

For the study of rotating machinery such as compressors and turbines, the instrument designer is frequently requested to supply a combination instrument which will measure total temperature, total pressure, static pressure, and flow direction. The use of such an instrument shortens testing time by eliminating some of the probe surveys required when using instruments that measure only a single quantity. Furthermore, because of space limitations associated with many experiments it is desirable that the probe be able to pass through a small hole and have the sensing elements located near the axis of rotation of the probe shaft.

Most of the combination-probe information reported in the literature has been concerned with the measurements of fluid pressures and flow direction. Bibliographies listing several articles concerning this type of combination probe are given in references 1 and 2. Examples of combination probes with temperature sensing elements as well as pressure and flow-direction elements are given in references 3 and 4.

This report presents design considerations and flow characteristics of a combination temperature, pressure, and flow-direction probe that offers some advantages over similar probes previously reported.

Probe flow characteristics are presented over a range of subsonic Mach numbers ($0.2 \leq M < 1$) as well as for Mach 1.4. Reynolds numbers ranged from 1×10^6 to 1×10^7 per foot (3×10^4 to 3×10^5 per cm). Gas stagnation temperature was near ambient.

Although the combination probe reported herein was developed primarily for use in compressor and turbine research, it is applicable wherever restrictions on space and requirements of multiple measurements exist.

DESIGN CONSIDERATIONS

General Requirements

The design of a combination probe involves several considerations other than those of the individual sensor flow characteristics.

Because most of the anticipated applications are in streams bounded by walls, the probe must pass through a wall to reach the point of measurement. The simplest shape of wall penetration is a small, circular hole. It is therefore desirable, in many applications, that the probe support be of a circular cross section and that the sensing head components fall within the projected circular area of the main support.

A second mechanical consideration is that the sensing points fall on or near the axis of rotation of the probe shaft so that the point of measurement does not move through a large arc during rotational positioning.

Stream blockage should be minimized by shaping the sensing end of the support to have a small frontal area and low drag coefficient (ref. 5).

The physical size of the tubular sensor inlet holes, the thermocouple shield bleed holes, and the flow direction sensing holes require consideration of the problems of plugging by particles in the stream as well as probe response time.

The design should also lend itself to common shop fabrication techniques, with reproducibility being an important requisite.

Total Temperature

A main consideration in a thermocouple design for stream total temperature is the choice between a shielded or unshielded configuration. Time response is the primary advantage of an unshielded design. However, for steady-state flow conditions, the shielded thermocouple design provides a higher recovery, affords protection in high-velocity flow and in handling, and does not exhibit the abrupt "step" in the recovery curve for supersonic flow. This step occurs when the support bow wave crosses the junction of an unshielded wedge configuration (ref. 6).

For a given thermocouple configuration, the recovery is primarily a function of the velocity over the thermocouple junction. Shielded probes reduce the free-stream velocity and exhibit a higher recovery than unshielded designs. However, the extent to which the velocity is reduced depends on the ratio of shield inlet area to bleed-hole outlet area. For a very small shielded thermocouple design, the minimum bleed-hole size may be established by the need to prevent plugging from stream particles rather than by the need for the best compromise between recovery and time response. The consideration of using shielding for reducing a radiation error has not been included in this discussion because the primary intended application does not involve significant differences between the gas and duct wall temperature.

Total Pressure

The two main considerations concerning total pressure tubes in high Reynolds number flows are the effect of flow misalinement and the apparent displacement of the measurement when probing a total-pressure gradient. The misalinement characteristic can be improved somewhat by an internal chamfer in the inlet of the total pressure tube. However, when the uncertainty in flow direction is greater than about 20°, a shielded type of tube is required (ref. 7).

The gradient problem is alleviated by decreasing the diameter of the total-pressure tube and locating the tube inlet as far upstream from its support as the design will permit (refs. 8 and 9).

Flow Direction

For flow direction measurement in one plane, the sensing elements normally used are two pressures on the surfaces of a wedge or cylinder or at the entrances to two tubes whose inlets are angled to the flow direction. All these elements provide adequate sensitivity except in low-pressure, low-velocity applications.

In order to minimize flow-direction measurement errors when probing in a steep velocity gradient, the flow-direction sensing holes should be located closely enough together so that the sensed pressure difference associated with the velocity gradient is small.

If the probe is to be used over a wide range of velocity, the machined wedge has an advantage over the angled tubes because the null position for the wedge is more nearly independent of velocity.

Static Pressure

Stream static pressure is more difficult to measure than total temperature, total pressure, and flow direction. To ensure an accurate static-pressure reading, it is desirable that the sensing element be many diameters upstream from the probe support, as in the Prandtl-type tube. Because the probe must pass through a small hole and have the sensing elements near the center line of rotation, most combination probes do not include the ability to measure stream static pressure. Static pressure is then obtained either from a separate probe or from wall static pressure taps.

However, if it is mandatory that the combination probe have the ability to measure static pressure, one of the angle-sensing holes is normally used as an indication of this pressure. Here, again, the wedge has an advantage over the angled tubes in that the sensing holes can be located on the wedge at a point which provides a closer measure of stream static pressure.

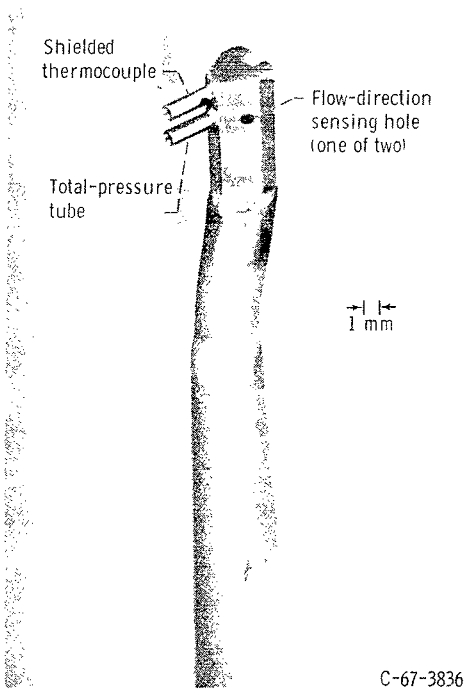

Figure 1. - Combination sensing probe.

PROBE DESIGN

A photograph of the combination probe is presented in figure 1. The probe head consists of a 60° included angle blunted wedge with flow-direction sensing orifices located on the wedge surface. Projecting upstream from the front of the wedge are an internally beveled total-pressure tube and a shielded thermocouple.

A detailed drawing of the probe is shown in figure 2. Note that the sensing head wedge and tubes fall within the projected area of the 1/4-inch (6 mm) diameter support. It can also be seen from the drawings that the probe support axis (which is also the axis of rotation for the probe) passes along the blunt leading edge of the sensing wedge.

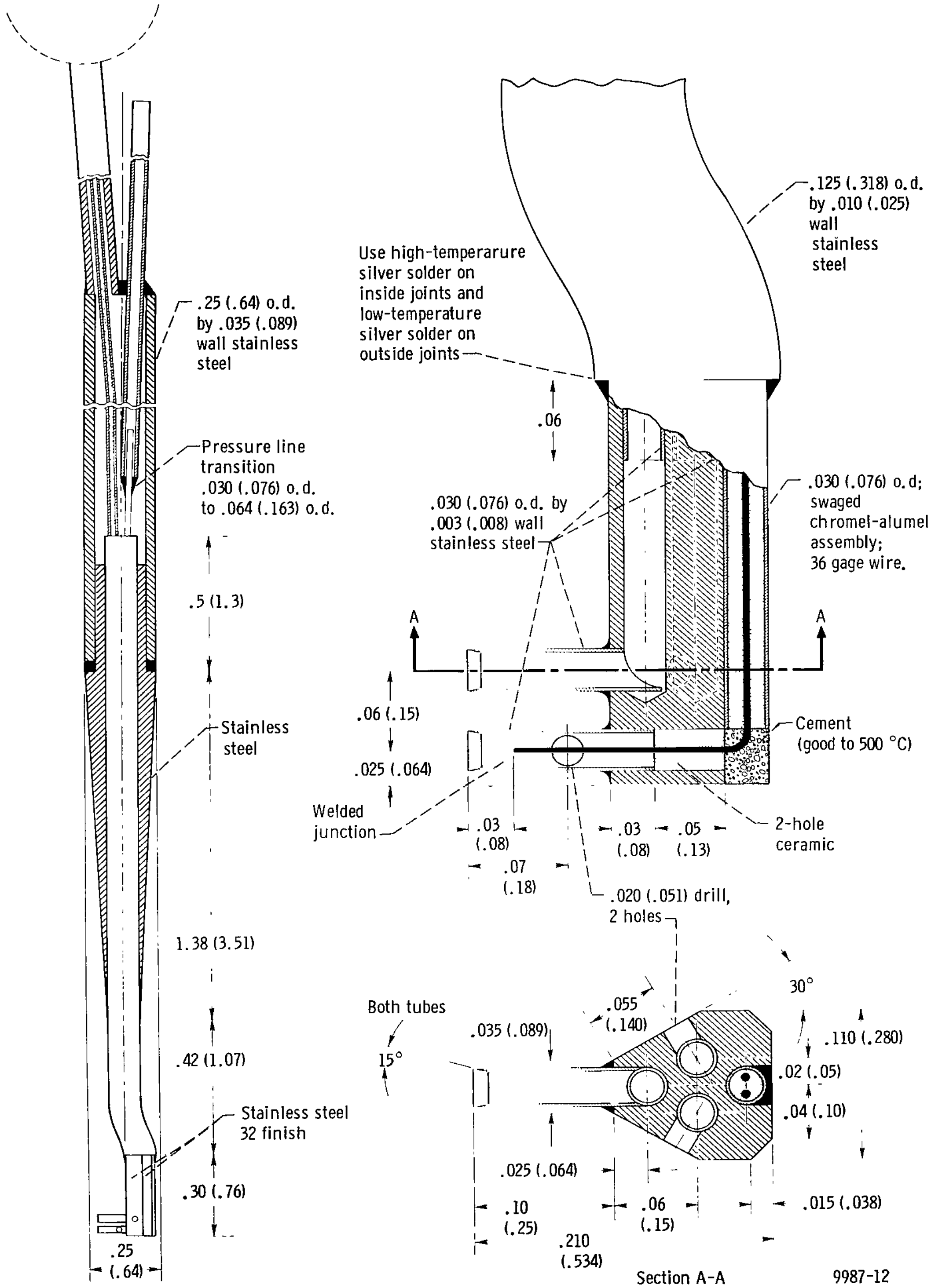

Figure 2. - Probe detail. Linear dimensions are in inches (cm).

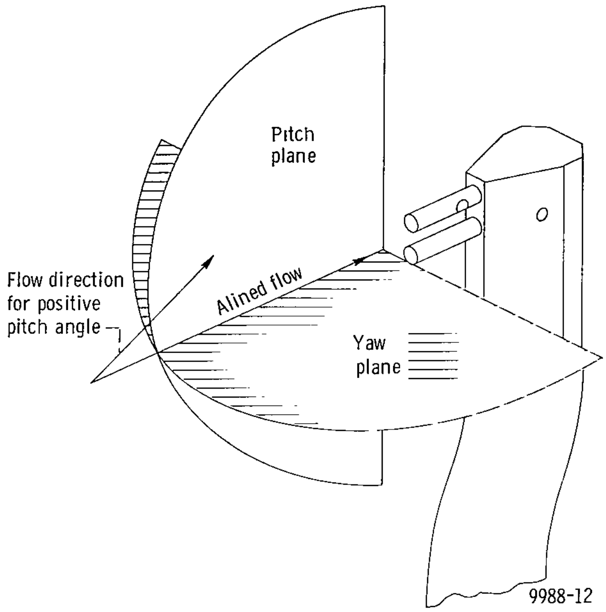

Figure 3. - Flow orientation nomenclature.

Later sections of this report will deal with the effects of nonalined flow on the probe characteristics. The flow orientation nomenclature related to those discussions is shown in figure 3.

TESTS

The characteristics of three probes were determined in the Lewis Instrument Research Branch small tunnel facility. This facility uses tunnels with test nozzles having throat sections of about 3 inches (8 cm). The flow in the nozzles and test regions was isentropic within the accuracy of the pressure and temperature measurements. Tests were made at near ambient temperature; dry air was employed for the supersonic tests to avoid condensation shocks in the test region. Most of the testing was done in the subsonic Mach number range. However, the report also includes some data for the thermocouple recovery correction factor taken at Mach 1.4.

Time response measurements were obtained by placing a streamlined shield over the probe in the stream and then heating the probe by passing heated air through the shield. After a steady-state probe temperature was reached, the hot-air shield was suddenly retracted by a pneumatic actuator, thus imposing a temperature step change on the probe. A more detailed description of the test apparatus and measuring system is given in reference 6.

RESULTS AND DISCUSSION

Temperature Measurement

Thermocouple recovery-correction factor. - In using thermocouple probes, it is convenient to correct for an aerodynamic recovery error by using a recovery-correction factor Δ.

$$\Delta = \frac{T_t - T_{ind}}{T_t} \tag{1}$$

where T_t is total temperature and T_{ind} is the indicated thermocouple junction temperature. All temperatures are absolute. In an application in which the junction has responded to the aerodynamic flow, and conductive or radiative heat exchange is not present, the quantity T_{ind} is equal to the adiabatic junction temperature, and T_t can be calculated from the indicated junction temperature and the value of Δ.

$$T_t = \frac{T_{ind}}{1 - \Delta} \tag{2a}$$

and since $\Delta << 1$,

$$T_t \approx T_{ind}(1 + \Delta) \tag{2b}$$

The recovery-correction factor of a thermocouple probe, in alined flow, varies primarily with stream Mach number, with a secondary effect of stream pressure. The recovery-correction factor for alined flow, at 1-atmosphere (1×10^5 N/m^2) stream pressure, will be termed the reference recovery-correction factor Δ_o.

The variation of Δ_o with Mach number M for the combination probe reported herein is presented in figure 4. The average value for the three probes is indicated by the solid line; the shaded region shows the range of variation of the three probes. This shading, to represent the range of variation of data, will be used throughout the report.

The dashed portion of the curve is an interpolation to a single measurement made at a Mach number of 1.4.

The value of Δ_o for this probe is about twice the value for larger, single-element probes of the same general design, where there was more freedom to optimize the ratio of shield inlet area to bleed-hole outlet area (ref. 10).

The variation of the recovery-correction factor with pressure, for alined flow, is

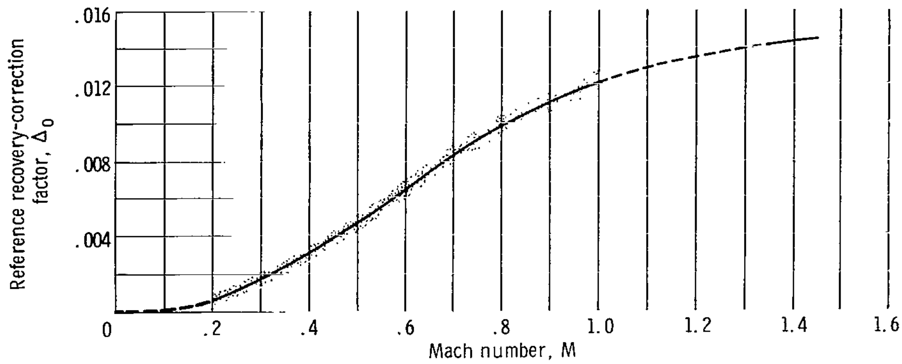

Figure 4. - Variation of reference recovery-correction factor with Mach number. Δ_0 is the recovery-correction factor at a total pressure of 1 atmosphere (1×10^5 N/m^2). Alined flow.

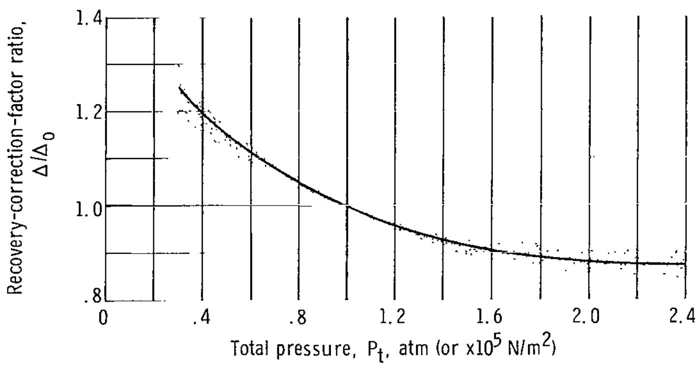

Figure 5. - Variation of recovery-correction-factor ratio with pressure. Δ_0 is the recovery-correction factor at 1 atmosphere (1×10^5 N/m^2). Alined flow. $0.6 \le M \le 0.9$ and $M = 1.4$.

shown in figure 5. Conductive heat exchange from the support is the most likely cause of this variation. This shielded thermocouple design shows less pressure effect than similar designs of references 6 and 10, and, in fact, more closely approaches the pressure effect on the unshielded wedge thermocouple configurations.

The variation of recovery-correction factor in yawed and pitched flow is presented in figures 6 and 7. The yaw data are symmetrical about the alined-flow (zero angle) axis, but the pitch data are not. This lack of symmetry about the zero-pitch axis is typical for a sensor located near the end of a support.

The shaded areas of figure 5 to 7 appear wide compared with that of the reference recovery-correction factor of figure 4. However, these figures represent only variations in a small correction.

<u>Thermocouple response time</u>. - A typical time response curve for the probe is shown in figure 8. Initially, there is a rapid response of the small thermocouple wire, which approximates a first-order system. But then the influence, through conduction, of the

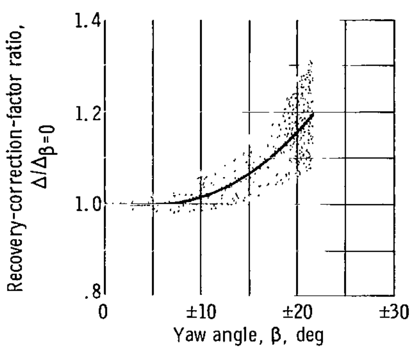

Figure 6. - Variation of recovery-correction-factor ratio with yaw angle. $0.3 \leq M \leq 0.9$ and $M = 1.4$.

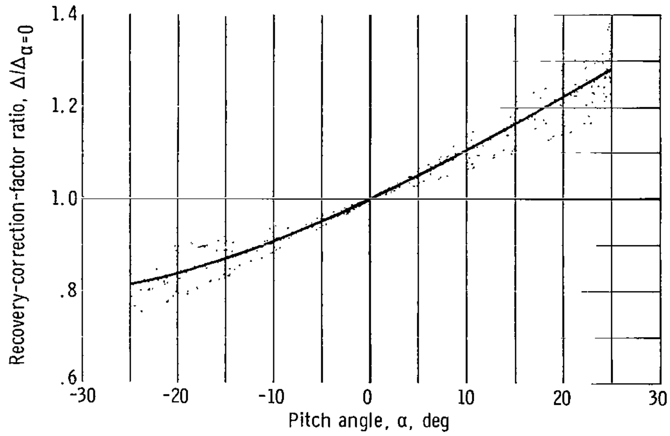

Figure 7. - Variation of recovery-correction-factor ratio with pitch angle. $0.3 \leq M \leq 0.9$.

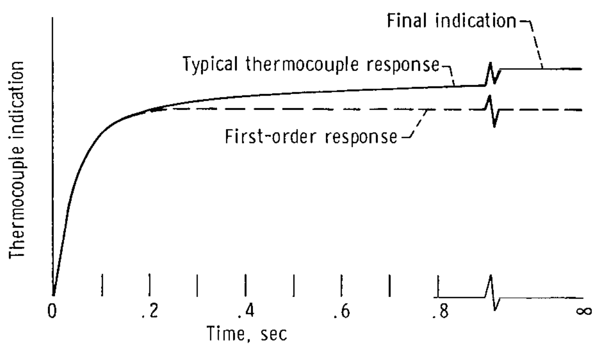

Figure 8. - Typical time response of thermocouple.

slower response of the support becomes apparent. The solid line is indicative of the overall probe response and the dashed curve represents the response that could have been expected if the support temperature were constant. The time response tests were run in subsonic flow and at 1 atmosphere (1×10^5 N/m^2) total pressure. The time constant of the first-order response curve (dashed curve) is 0.05 second, but the overall response was about 4 seconds to reach 99 percent of the final indication.

Response time for the probe reported herein is presented primarily to aid in the determination of maximum traversing speed when the probe is used in a continuous traverse.

The influence of the support on the overall time constant could be decreased by decreasing the heat conduction between the thermocouple wire and the support. Normally, this would be accomplished by having a large length-to-diameter ratio of the wire exposed to the flow in the shield. However, for the probe reported herein, the shield size, bleed hole location, and fabrication considerations limited the application of this principle.

To avoid the introduction of additional factors that would affect response as well as accuracy, proper care must be observed in fabrication to avoid the possibility of short-circuited wires in the small, swaged assembly, and the possibility of having the thermocouple junction touch the shield.

Total Pressure Measurement

The variation in indicated total pressure with yaw angle is presented in figure 9, where p_t is total pressure, $p_{t,ind}$ is indicated total pressure, and p_s is stream static pressure. The figure shows that the probe is insensitive to misalinement to within 1 percent of impact pressure at yaw angles β up to 17°. Reference 7 gives a corresponding value of 27.5° for 1 percent error for a 15° half-angle beveled-inlet, cylindrical total-pressure tube. However, the tube of reference 7 had a 30-times larger outside diameter and had an inside to outside diameter ratio of 0.2 compared with 0.8 for this probe.

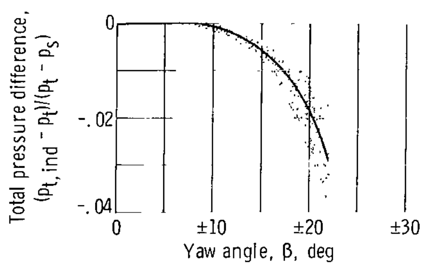

Figure 9. - Variation in total pressure difference with yaw angle. $0.3 \leq M \leq 0.9$.

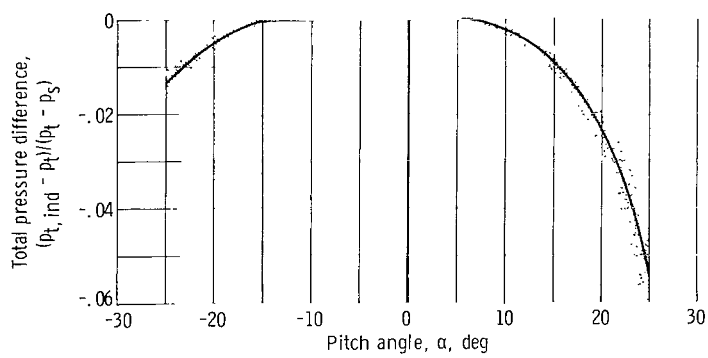

Figure 10. - Variation in total pressure difference with pitch angle. $0.3 \leq M \leq 0.9$.

The variation in indicated total pressure $p_{t,ind}$ with pitch angle α is shown in figure 10. The lack of symmetry about the zero axis is typical for a total-pressure tube located near the end of a support.

Flow Direction Measurement

The variation in yaw angle with wedge surface-pressure difference is shown in figure 11. The designations p_1 and p_2 indicate the pressure measured by the directional sensing holes on the wedge surfaces. The slope of the line of figure 11 is commonly called the flow-angle sensitivity and has a value of 5 percent of impact pressure per

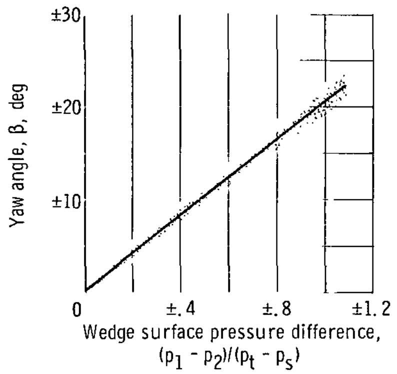

Figure 11. - Variation in wedge surface pressure difference with yaw angle. $0.3 \leq M \leq 0.9$.

degree of yaw misalinement. This value compares favorably with reported flow direction sensitivities for other probes (refs. 11 and 8).

For the three probes tested, with pitch angle α set at zero, the null position for yaw varied less than $1/2^{\circ}$ for $0.2 \leq M < 1$. As the pitch angle was varied $\pm 25^{\circ}$, the null position for yaw varied less than $3/4^{\circ}$ for $0.3 \leq M < 0.9$. Best flow direction measurements are obtained if the probe is null balanced approximately in the middle of the expected Mach number range.

Static-Pressure Measurement

As stated previously, combination probes, which are designed to pass through a small hole, usually do not incorporate the ability to measure static pressure. However, when required, the pressures at the flow direction sensing holes may be related to static pressure. Figure 12 shows the relation between stream static pressure and measurable probe pressures when the probe is alined with the fluid stream. The ordinate is in the form of a pressure coefficient, where $(p_1 - p_s)$ is the difference between wedge surface pressure and stream static pressure, and $(p_{t,\,ind} - p_1)$ is indicated impact pressure. The abscissa is an indicated pressure ratio related to Mach number.

It is seen from figure 12 that at low Mach numbers ($M < 0.4$) the wedge pressure is lower than stream static pressure. This is in agreement with reported results for the case where the sensing holes are located toward the rear of the wedge (ref. 12). As Mach number is increased, the wedge pressure indication becomes more positive. This result is typical of wedge pressure coefficients (ref. 13). It should be noted that the slope of the curve becomes excessive at the higher Mach numbers.

An undesirable feature of this probe is the insertion or stem effect. As the probe is

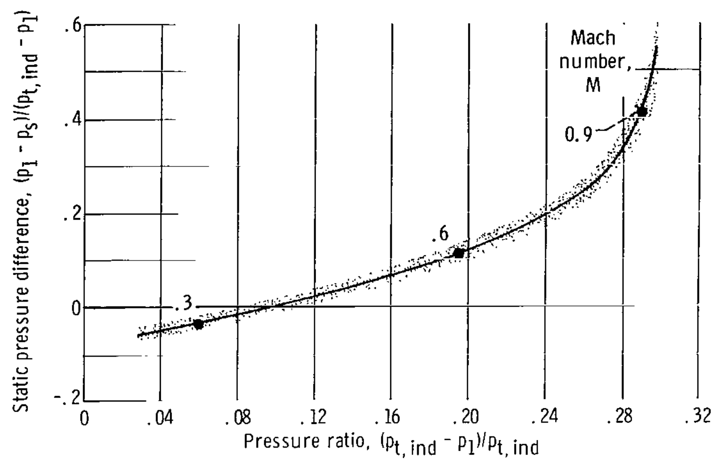

Figure 12. - Variation in static pressure difference with probe measurables. Alined flow.

inserted into a fluid stream, there is a change in stream blockage and a change in cross flow along the probe stem. And because the wedge sensing holes are located near the support, these changes affect the static-pressure measurement. For example, the ordinate of figure 12 represents the sensing hole indication at the centerline of a $3\frac{1}{2}$-inch (9-cm) diameter free jet of constant static pressure. The probe was used in a survey across this jet. The sensing hole indication $(p_1 - p_s)/(p_{t,\,ind} - p_1)$ varied linearly from -5 to +5 percent from the centerline value. This effect is discussed in reference 1. The user should, therefore, use caution concerning the accuracy of static-pressure measurements with probes of this type.

Fixed-Position Application

Although this probe is primarily intended to be used with an actuator that supplies linear and/or rotational positioning, it may be used to a limited extent in a fixed position. At zero pitch, measured pressures can be used to obtain flow parameters as follows:

(1) The value for the yaw angle β can be obtained from probe measurables using figure 13. This figure is another way of presenting figure 11 using probe measurables.

(2) With this value of β and probe measurables, use figure 14 to obtain an ordinate value and calculate impact pressure $(p_t - p_s)$.

(3) Calculate the true total pressure p_t from the appropriate ordinate of figure 9.

(4) Calculate the stream static pressure from this value of p_t and from the quantity $(p_t - p_s)$ previously obtained.

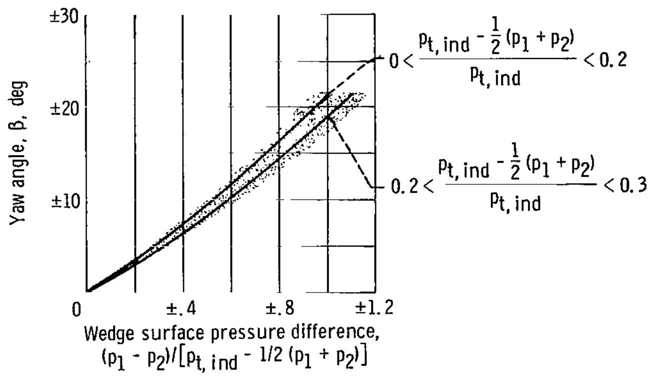

Figure 13. - Variation to wedge surface pressure difference, in terms of probe measurables, with yaw angle. $0.3 \leq M \leq 0.9$.

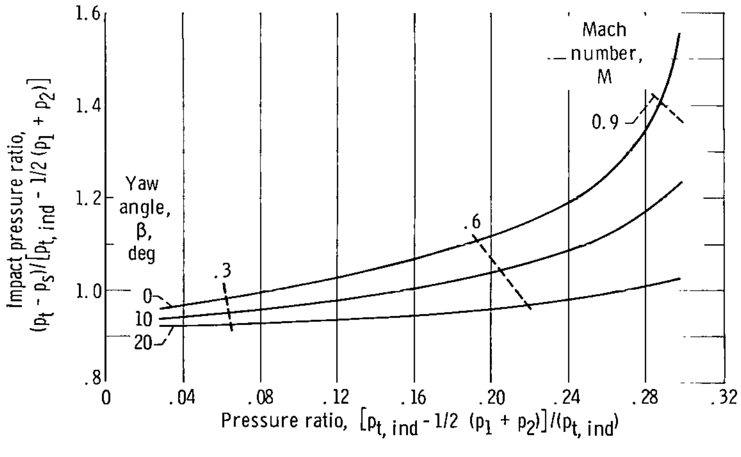

Figure 14. - Variation in impact pressure with probe measurables.

PROBE MODIFICATIONS

Boundary-Layer Probe

The probe configuration reported herein can serve as a basic design that may be modified for other specific applications. One such modification is shown in figure 15. The application was for measuring boundary-layer total pressure and flow direction in a flowing liquid. Because of the forces associated with the flowing liquid, a rugged probe was required. The probe was modified by removing the thermocouple assembly and the end portion of the wedge which contained the thermocouple assembly. The total-pressure tube configuration was changed by using a 0.02-inch (0.05-cm) outside diameter tube and forming it into an approximate elliptical cross-section shape with a 0.025-inch (0.063-cm) major axis and a 0.010-inch (0.025-cm) minor axis. The boundary layer which was surveyed was the boundary layer on the wall adjacent to the probe insertion hole.

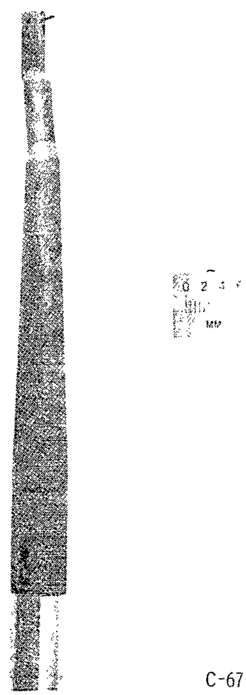

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Figure 15. - Boundary-layer probe.

Thermocouple Design Change For Low Reynolds Number Flow

Because the difference between total and static temperature is small at low stream velocities, a shielded, high-recovery thermocouple design is not necessary for applications in a low-velocity stream. Furthermore, if the application is in a stream that is also at low pressure, additional consideration of conduction error (ref. 14) as well as the secondary pressure effect on the recovery factor for shielded probes, may warrant the use of an unshielded thermocouple design. The point at which such a modified design becomes necessary depends on the specific application and involves several considerations. In general, an unshielded design should be considered when the stream Mach number is less than 0.2 and the static pressure is less than 0.2 atmosphere (2×10^4 N/m^2). This is especially true when there is a large enough temperature gradient between the gas and the probe mounting heat sink to induce a significant conduction error.

The physical modification of the probe is made by lengthening the thermocouple wire by 0.03 inch (0.08 cm) to bring the junction of the thermocouple to the plane of the total-pressure tube inlet. The tubular shield, insulator, and cement are removed, and the span of the wedge is shortened by 0.04 inch (0.10 cm). This will expose about a 0.2-inch (0.5-cm) length of wire (for each leg) to the stream flowing past the end of the probe.

CONCLUDING REMARKS

This report presents the design features and characteristics of a small combination sensing probe for measuring total temperature, total pressure, and flow direction of a gas stream. It also shows that with proper consideration a flow-direction sensing hole pressure can be used to determine static pressure. Experimental data are presented for the aerodynamic recovery and time response of the temperature sensor, the flow-angle sensitivity of the total-pressure sensor, and the sensitivity of the flow-direction wedge. Data were obtained over a subsonic Mach number M range of $0.2 \leq M < 1$ as well as at $M = 1.4$.

The probe is intended to be used primarily in an actuating system capable of linear and/or rotational positioning, but information is presented whereby the probe may be used in a fixed position to determine stream parameters from measured quantities.

The choice of the type of individual sensor to measure temperature, pressure, and flow direction was made primarily on the basis of past experience and necessary compromises in combining the individual sensors on one support. The major compromises were made in regard to the size and position of the thermocouple shield bleed holes, which influence recovery and response characteristics.

The probe design, as presented, should find many applications in the field of experimental fluid mechanics. It also can be modified for other, related applications.

The data in this report present the test results of three probes manufactured from a single source using figure 2. Because this represents a limited sample, it is advisable that additional probes built from the drawing (fig. 2) be calibrated to determine any major deviation from the curves presented herein.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, June 21, 1968,
126-15-02-07-22.

REFERENCES

1. Folsom, R. G.: Review of the Pitot Tube. Trans. ASME, vol. 78, no. 7, Oct. 1956, pp. 1447-1460.
2. Benedict, R. P.: Pressure and Its Measurement. Electro-Technology, vol. 80, Oct. 1967, pp. 70-90.
3. Tysl, Edward R.; Schwenk, Francis C.; and Watkins, Thomas B.: Experimental Investigation of a Transonic Compressor Rotor with a 1.5-Inch Chord Length and an Aspect Ratio of 3.0. NACA RM E-54L31.
4. Petrash, Donald A.; Davison, Elmer H.; and Schum, Harold J.: Investigation of Turbines Suitable for Use in a Turbojet Engine with High Compressor Pressure Ratio and Low Compressor-Tip Speed. VIII-Internal Flow Conditions of a Two-Stage Turbine with a Downstream Stator. NACA RM E57I19.
5. Krause, Lloyd N.; and Gettelman, Clarence C.: Effect of Interaction Among Probes, Supports, Duct Walls and Jet Boundaries on Pressure Measurements in Ducts and Jets. ISA Proc., vol. 7, 1952, pp. 138-141.
6. Stickney, Truman M.: Recovery and Time-Response Characteristics of Six Thermocouple Probes in Subsonic and Supersonic Flow. NACA TN 3455, 1955.
7. Gracey, William; Letko, William; and Russell, Walter R.: Wind-Tunnel Investigation of a Number of Total-Pressure Tubes at High Angles of Attack. Subsonic Speeds. NACA TN 2331, 1951.
8. Gettelman, Clarence C.; and Krause, Lloyd N.: Considerations Entering into the Selection of Probes for Pressure Measurement in Jet Engines. ISA Proc., vol. 7, 1952, pp. 134-137.

9. Livesey, J. L.: The Behavior of Transverse Cylindrical and Forward Facing Total Pressure Probes in Transverse Total Pressure Gradients. J. Aeron. Sci., vol. 23, no. 10, Oct. 1956, pp. 949-955.

10. Glawe, George E.; Simmons, Frederick S.; and Stickney, Truman M.: Radiation and Recovery Corrections and Time Constants of Several Chromel-Alumel Thermocouple Probes in High-Temperature, High-Velocity Gas Streams. NACA TN 3766, 1956.

11. Schulze, Wallace M.; Ashby, George C., Jr.; and Erwin, John R.: Several Combination Probes for Surveying Static and Total Pressure and Flow Direction. NACA TN 2830, 1952.

12. Keast, F. H.: High-Speed Cascade Testing Techniques. Trans. ASME, vol. 74, no. 5, July 1952, pp. 685-693.

13. Gettelman, Clarence C.; and Krause, Lloyd N.: Characteristics of a Wedge with Various Holder Configurations for Static-Pressure Measurements in Subsonic Gas Streams. NACA RM E51G09, 1951.

14. Scadron, Marvin D.; and Warshawsky, Isidore: Experimental Determination of Time Constants and Nusselt Numbers for Bare-Wire Thermocouples in High-Velocity Air Streams and Analytic Approximation of Conduction and Radiation Errors. NACA TN 2599, 1952.

NASA-Langley, 1968 —— 14 E-4441

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